February 2, 1888.

Professor G. G. STOKES, D.C.L., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read :—

I. "On Tidal Currents in the Ocean." By J. Y. BUCHANAN, M.A., F.R.S.E. Communicated by the late Sir FREDERICK EVANS, K.C.B., R.N., Hydrographer to the Admiralty. Received March 24, 1884. Received after revision January 23, 1888.

It is frequently asserted and commonly believed that tidal currents do not exist in the open ocean or in waters remote from land. Oceanic currents, that is, streams which set more or less constantly in one general direction, are well-known and, from their importance to navigation, have been the objects of much study. Chief among these may be mentioned the Gulf Stream and the Equatorial Currents in both oceans. The data on which almost all our information connected with these streams rests are furnished by the logs of ships traversing them. When the position of the ship is determined from day to day by good astronomical observations on the one hand, and the courses and distances sailed are carefully observed and noted on the other, it is usual, after allowing for known perturbing causes, to ascribe the differences between the positions as ascertained by "observation" and by "dead reckoning" to the effect of a current. As in the ordinary routine of a sea-going ship, the positions are made up from noon to noon, the strength and direction of the current so deduced is the integral resultant "set" of the previous twenty-four hours. The direction and strength of the current may have changed in any way during that time, and it would be nearly impossible to detect such changes. The period of twenty-four hours corresponds closely with that of the tidal wave, consequently in the time elapsing between two successive noons, whatever effect may have been due to a tidal cause will have completely reproduced itself twice over and a very little more. The resultant current due to the tide during the two complete periods will be nothing, and the only resultant current affecting the day's reckoning will be that due to the difference be-

tween the solar and lunar day. From the nature of the observations the effect due to this would not be easily detected. It is evident then that the ordinary method of observing oceanic currents is such as completely to cloak any tidal effect which may exist. The proximate source of energy for the production of tidal currents is the tidal wave.

Storm waves are confined to the surface of the ocean, and break only in comparatively shallow water. The tidal wave affects the deepest oceans to the bottom. It might, therefore, be reasonably expected that, in passing over many of even the deeper ridges which traverse the ocean bed, its character as an undulation would be modified with the production of a true tidal current. We know that in the shallow water surrounding the land and in the bays and inlets which indent its coasts, a portion of the tidal energy is dissipated by the partial transformation of the wave into currents.

In littoral waters these currents are necessarily exaggerated by the confinement produced by the neighbouring land; but the presence of a shoal alone, without any dry land in the vicinity, ought to be sufficient to produce well-marked and regular tidal currents.

Considerations of this nature determined me to take the first opportunity which might offer of putting the matter to the test of observation.

Thanks to the hospitable invitation of the India Rubber, Gutta Percha, and Telegraph Works Company, of Silvertown, I had the good fortune to spend the months of October and November, of 1883, on board the s.s. "Dacia," one of their excellently equipped cable ships, which, along with the s.s. "International," was sent out to connect Cadiz with the principal islands of the Canary Group by means of a telegraph cable. The whole expedition was under the command of the Company's Telegraphic Engineer-in-chief, Mr. Robert Kaye Gray, to whom I am particularly indebted for the facilities which were afforded me in carrying out this and many other investigations, and I beg publicly to tender him my best thanks.

In the course of the sounding operations carried out with a view of gaining a thorough acquaintance with the depth and nature of the sea bottom, over which it was proposed to lay the cable, many remarkable inequalities were met with. Perhaps the most striking was one which was called the "Dacia Bank," after the ship on which it was discovered. This bank, which occupies a surface of 50 square miles with less than 100 fathoms of water on it, rises rapidly from the prevailing depth of 1800 or 1900 fathoms to within 500 fathoms of the surface, whence the slope is very abrupt and in many places precipitous to within 100 fathoms of the surface. As the bank lay close to the proposed route of the cable, two days were spent in surveying it carefully. In order to have a fixed point to refer the soundings to, a

mark-buoy was anchored in 175 fathoms, just outside the precipitous edge of the bank.

On the afternoon of the 21st October, 1883, I spent several hours in one of the ship's boats made fast to this buoy, and during that time I made frequent observations of the rate and direction of the surface current as well as of the general direction of the under current. (See Table I.)

It had been observed during the previous day and night that at times the current set strongly to the southward, at other times became nearly slack and even ran to the northward. While the boat was being lowered and got away the ship drifted very slowly to the northward past the buoy and against a light northerly air blowing at the time. When the boat was made fast to the buoy the current was found setting to the northward, against the wind and sea, and measures were immediately taken for determining its direction and velocity at frequent intervals. For this purpose an ordinary life-buoy was attached to the end of a line which was marked at every fifth fathom with a piece of wood, which also served the purpose of keeping the line afloat and of showing whether it was going out straight or not. Although the wind was only barely perceptible, it was found to retard the life-buoy. An arrangement of canvas was accordingly weighted and hung down in the axis of the buoy. This greatly increased its hold on the water and made its movements dependent only on the current. The direction of the current was observed with a pocket azimuth compass for use on land. Although there was hardly any wind, there was a considerable swell coming up from the north, but it did not produce any motion sufficiently violent to interfere with the use of the compass. In order, however, to remove any uncertainty, which might have existed with regard to the correctness of the bearings so observed, I always took a bearing of the sun at the same time, as an index of the trustworthiness of the current observations.

No accurate measurements were made of the under current, but while the surface current was being observed a tow-net lashed to a sounding line was lowered to 35 fathoms for one hour, and to 70 fathoms also for an hour. The directon taken by the sounding line showed that down to 75 fathoms the direction inclined slightly more to the eastward than the surface current, and its strength seemed to be slightly greater.

The observed bearings of the sun give for the local variation 17° W., 17° W., 21° W., 21° W. According to the chart the variation is 19° W. The bearings therefore as determined in the boat may be depended on to a quarter of a point.

Time was taken by a watch set to local time. In letting the current log run out care was taken to put no strain on the line, so

Table I.—Observations of Surface Current on the Dacia Bank, lat. 31° 10′ N., long. 13° 14′ W. 21st October, 1883.

Time P.M. (local)		1 hr. 55 m.		2 hr. 15 m.			2 hr. 40 m.			3 hr. 30 m.			4 hr. 6 m.		
Sun's bearing (magnetic)......		N. 235° E.		N. 240° E.			N. 250° E.			N. 260° E.					
,, ,, (true)		N. 218° E.		N. 223° E.			N. 229° E.			N. 239° E.					
,, variation (apparent)		17° W.		17° W.			21° W.			21° W.					
Direction of current (magnetic)		N. 30° E.		N. 30° E.			N. 60° E.			N. 75° E.			N. 120° E.		
,, ,, (true)		N. 11° E.		N. 11° E.			N. 41° E.			N. 56° E.			N. 101° E.		
	Fathoms.			min.	sec.	Diff. sec.	min.	sec.	Diff. sec.	min.	sec.	Diff. sec.	min.	sec.	Diff. sec.
Time when each mark on the line passed into the water.	0	..	..	0	0	—	0	0	—	0	0	—	0	0	—
	5	..	..	0	40	40	0	55	55	1	30	90	0	50	50
	10	..	..	1	20	40	2	0	65	2	5	35	2	0	70
	15	..	..	1	55	35	3	5	65	3	15	70	3	0	60
	20	..	..	2	25	30	4	10	65	4	40	85	4	2	62
	25	..	..	2	55	30	5	15	65	5	50	70	5	6	64
	30	..	..	3	25	30	6	15	60	6	55	65	5	57	51
	35	..	..	4	5	40	7	5	50	7	55	50	6	51	54
	40	..	..	4	50	40	7	55	50	9	10	75	7	45	54
	45	..	..	5	30	40	8	45	50	10	12	62	8	35	50
	50	..	..	6	5	35	9	45	60	11	20	68			
	55	..	..	6	50	45									
Line taut	50	..	..	..		..	10	0	..	11	30	..	9	45	
	55	..	..	7	5										
Current (knots per hour)		..	..	0·47			0·30			0·26			0·30		

that the intervals at which successive marks passed out of the boat must not be compared too rigidly. When the whole length of line, 50 or 55 fathoms, as the case might be, was paid out, it was allowed to tauten itself, and the time observed when it became taut. The bearing of the float was then taken, and that of the sun immediately afterwards. The results of the observations are summarised in the following table.

Table II.—Summary of Current Observations made on the Afternoon of the 21st of October, 1883, on the edge of the Dacia Bank, lat. 31° 10′ N., long. 13° 34′ W., depth 175 fathoms.

Time (P.M.)	1 hr. 55 m.	2 hr. 15 m.	2 hr. 40 m.	3 hr. 30 m.	4 hr. 6 m.
Direction (true)....	N. 11° E.	N. 11° E.	N. 41° E.	N. 56° E.	N. 101° E.
Rate in knots per hr.	..	0·47	0·30	0·26	0·30

"It will be seen from these observations that, in two hours, the current had shifted its direction through 90°, and had passed through a minimum velocity of 0′·26 per hour without there having been any period of 'slack water.' The observations are too few in number to make it worth while submitting them to analysis, but a little study of them will show that they indicate a current which is the resultant of a constant current and a periodic one. A constant current running S.E. by E., combined with a tidal current running N.N.W. and S.S.E., the maximum velocity of which, in either direction, is twice that of the permanent current, would give a resultant current agreeing fairly with that observed."*

In these circumstances, during a complete tidal interval the water flows along an S-like path, and in the twenty-four hours it describes two such figures, and moves on in a zig-zag course. It is apparent that the integral drift in the twenty-four hours is that due to the constant current alone independently of the tidal current. The same holds for twelve hours. Hence, if observations are carried on at frequent and regular intervals for twelve hours, we are able to determine both the constant current and the tidal current superposed on it, and it is to be hoped that when they can be made they will not be neglected by surveying ships and telegraph ships.

Many banks are already known in the North Atlantic on which such observations could conveniently be made, and there are probably many more scattered about the ocean, for instance, on the ridge called after the U.S.S. "Dolphin," which extends along a somewhat crooked line from the Azores to Tristan da Cunha. It is of course important to have fine weather; then the boat in which the observations are made

* 'Edinburgh, Roy. Soc. Proc.,' vol. 13, 1886, p. 437.

should, if possible, be moored with two lines to prevent swaying. In cable ships large mushroom anchors with heavy chain bridles are in common use. If one of them is dropped, a ship's boat may be anchored to it with no more line than is required to reach the bottom, and be in no danger of swaying. Similar observations should be made also from a boat anchored in very deep water.

No measurements were made of the under current, but by sinking a tow-net made fast to a sounding line, it was seen to be running in the same direction as the surface current, and apparently with much the same velocity. In the channels between the Canary Islands where even on the shallowest ridges the water is over 1000 fathoms in depth, the tidal current reaches to the very bottom, and its scouring action is shown by the nature of the bottom. To seaward in 1800 to 2000 fathoms the bottom is a fine *Globigerina* ooze, which gets coarser and sandier as the water shoals in the channels, till on the summit ridge there is generally no deposit at all, and the bottom is rock or coral coated with black oxide of manganese. Round the western end of Tenerife the tide runs violently causing rips and overfalls. Much rocky ground is met with in the North Atlantic in depths of even 1300 and 1400 fathoms, especially on the ridge which extends through the whole length of that ocean. It is not unlikely that the summit edge of this ridge is swept clean through the greater part of its length, and it must be remembered that the removal of sediment from one part of the ocean bottom means its deposit in greater abundance in others, and especially in hollows in the neighbourhood of the ridge. Hence a sounding in "ooze or clay" in one position furnishes no argument against the trustworthiness of another sounding in the vicinity and in equally deep water on "rock" or "hard ground." Such ridges are great enemies to telegraph cables, for while the tidal currents keep the rock-surface clean, they also tend to give the cable an oscillating or surging motion, which is apt to bring it in rubbing contact with the rock-surface and so to wear it through. On the other hand these currents, in sweeping clean the rocky eminences at the bottom of the ocean, prepare a lodging place for deep-sea corals, and bring food to them when settled, thus enabling them to build up their pillar-like banks, a very fine example of which was discovered and surveyed by the "Dacia" on the 12th October, 1883. It lies in lat. 34° 57′ N., long. 13° 57′ W., and the shoalest sounding was 435 fathoms. The surface of the bank was locally very rough, and sloped gradually to the edge in about 550 fathoms, when it terminated in an actual precipice, dropping to 835 fathoms in one place.

The coral on this bank was living and growing in the greatest luxuriance, and many specimens which were brought up showed that the living corals were growing on a mass of dead ones. There can

therefore be little doubt that in this case we have a submarine bank which is in vigorous growth towards the surface, and which has been in existence long enough to have risen through a height of about 300 fathoms or 1800 feet. I have little doubt that in a large number of the coral islands of the Pacific, the intermediate platform between the tropical reef-building coral and the volcanic peak, plateau, and ridge, which most probably form the foundation, is formed by these deep-sea corals largely assisted by annelids, especially Serpulæ, which secrete calcareous tubes. The tidal currents assist their growth both by bringing the animals nourishment and by removing light *débris* which might choke them.

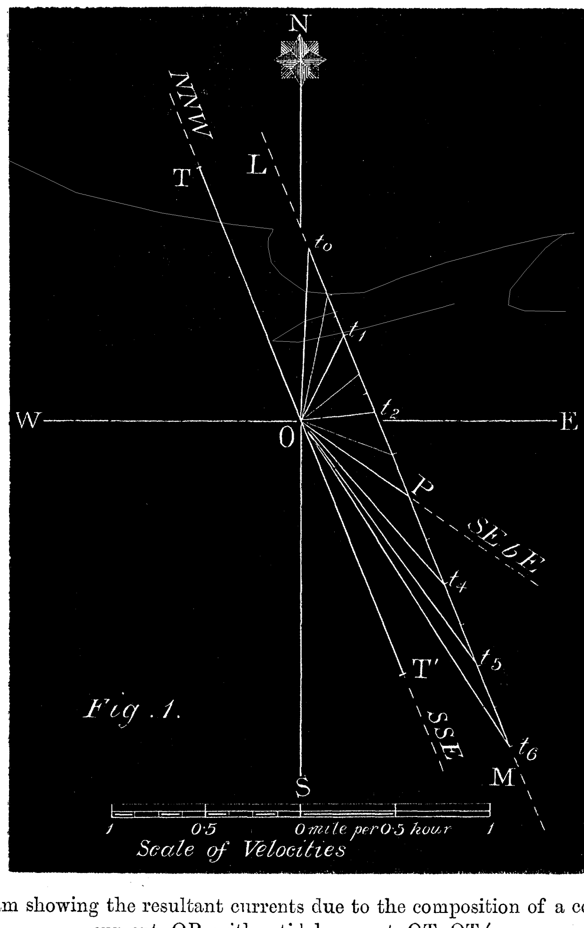

Diagram showing the resultant currents due to the composition of a constant current, OP, with a tidal current, OT, OT.′

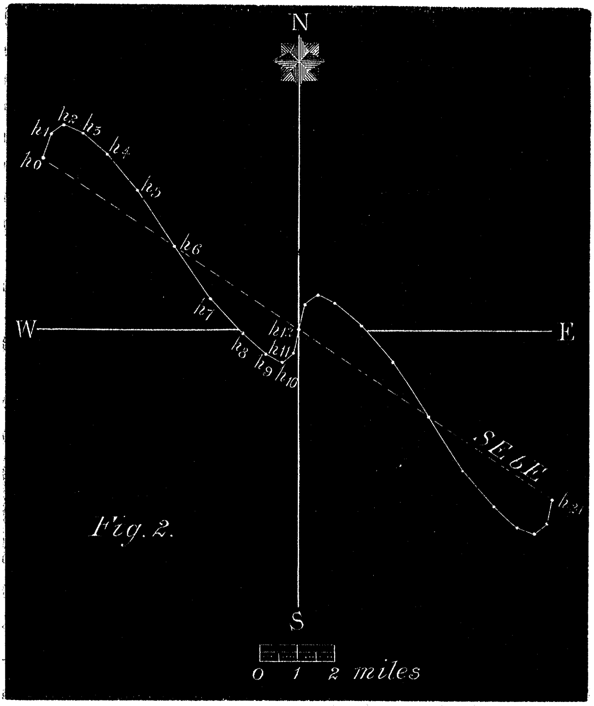

Fig. 2.

Diagram showing the path described in twenty-four hours by a particle under the influence of the tidal and constant currents of fig. 1.

II. "On the Spectrum of the Oxyhydrogen Flame." By G. D. LIVEING, M.A., F.R.S., Professor of Chemistry, and J. DEWAR, M.A., F.R.S., Jacksonian Professor, University of Cambridge. Received January 18, 1888.

(Abstract.)

In a former communication the authors described simultaneously with Dr. Huggins the strongest portion of the spectrum of water, subsequently they described a second less strong but more refrangible section of the same spectrum. M. Deslandres has noticed a third still more refrangible section. The authors now find that the spectrum extends, with diminishing intensity, into the visible region on the one hand, and far into the ultra-violet on the other. These faint parts of the spectrum they have photographed, using the dispersion of a single calcite prism and a lengthened exposure; and in the present communication they give a map of the whole extent observed, and a list of wave-lengths of upwards of 780 lines.

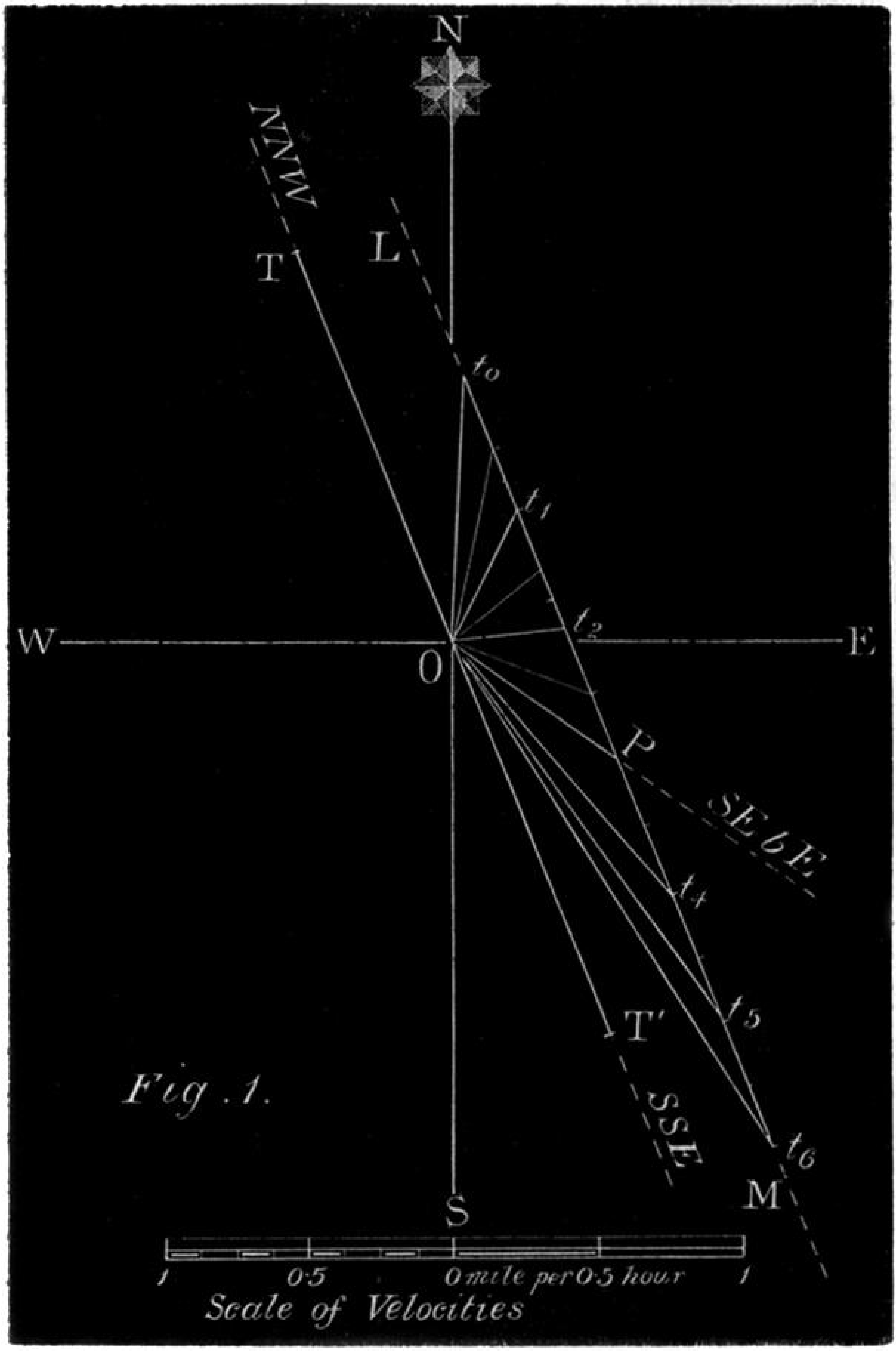

Diagram showing the resultant currents due to the composition of a constant current, OP, with a tidal current, OT, OT.′

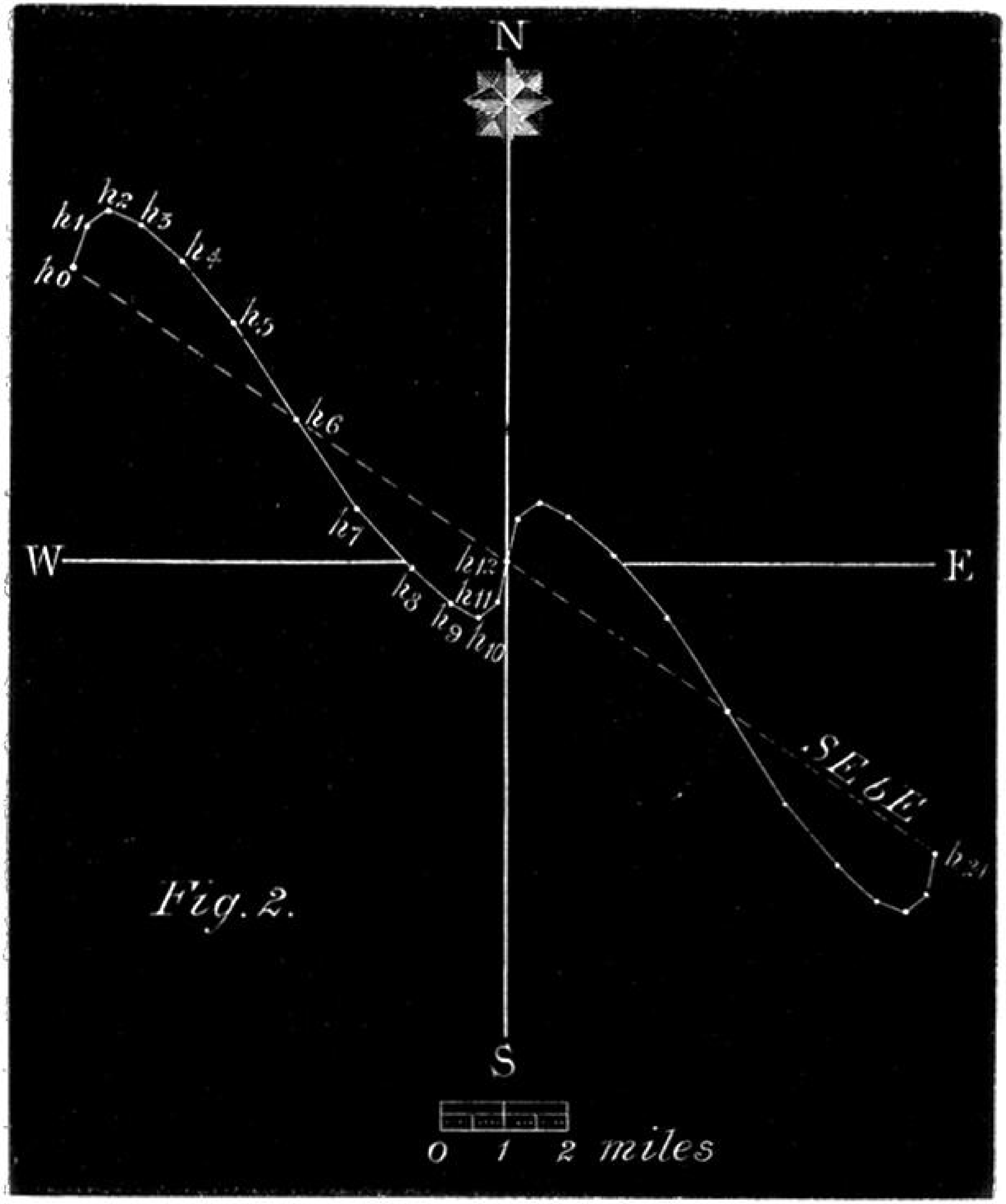

Diagram showing the path described in twenty-four hours by a particle under the influence of the tidal and constant currents of fig. 1.